Lunar Regional Pyroclastic Deposits: Evidence for Eruption from Dikes Emplaced into the Near-Surface Crust

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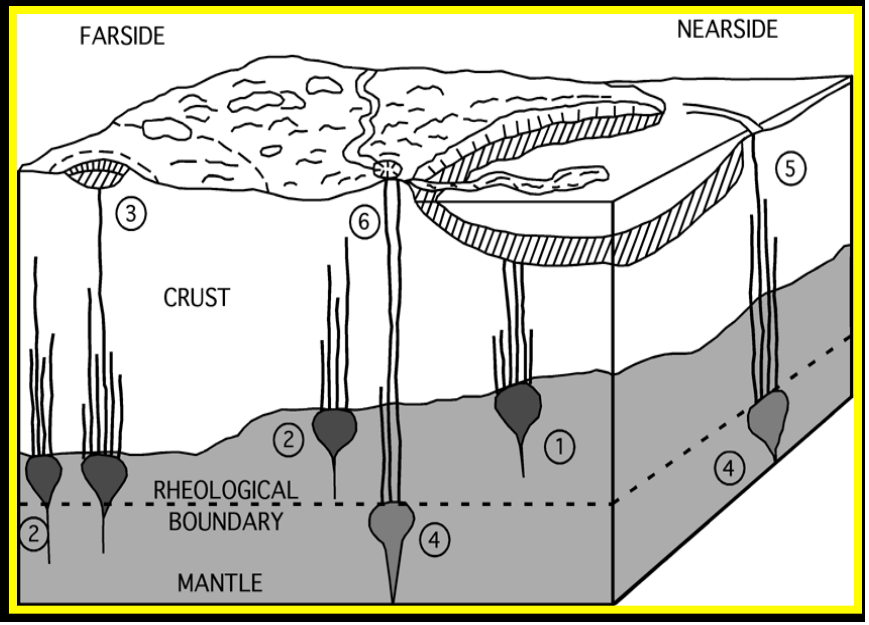
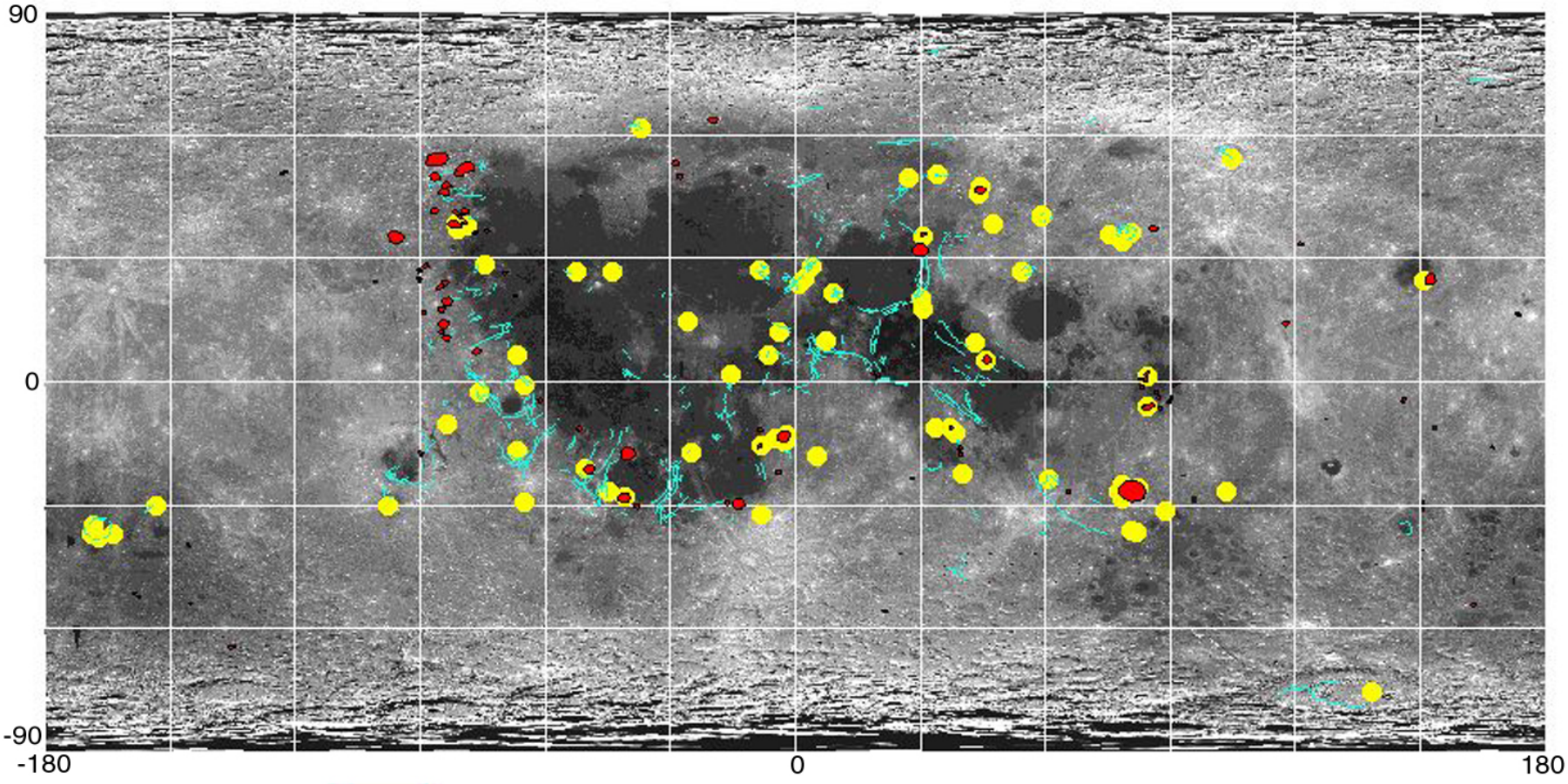
Importance of Explosive Volcanic Eruptions

- Volatile content: Planetary body, mantle, crust, magma.
- Fractionation processes:
  - Volatile formation, concentration, loss.
- Magma behavior: Melting, ascent, eruption.
- Style of eruption: Strombolian, vulcanian, etc.
- Nature of eruption processes:
  - Fountain optical density.
- Deposits and products:
  - Duration, range.
- Modification processes:
  - Aftermath: alteration, mixing.
- Resources:



Lunar Pyroclastic Deposits



Floor-fractured craters

Fault/Graben (Wilhelms, 1987)

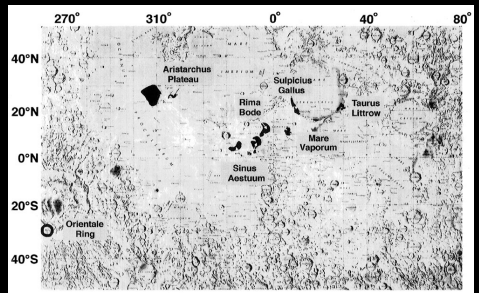
Pyroclastic Deposits

Distribution of
Lunar Pyroclastic Deposits

Lisa Gaddis LPI

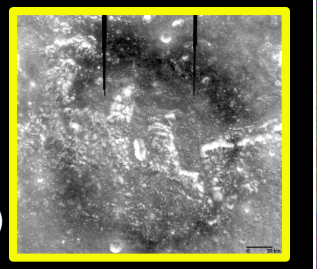
Lunar Pyroclastic Deposits: Modes of Occurrence:

- Smaller, more *isolated* deposits:
  - Eruption styles related to dike and sill emplacement, including strombolian, hawaiian, and vulcanian activity.
- Intermediate-scale *circular* deposit:
  - ~154 km diameter Orientale dark ring: pyroclastic deposit centered on a linear depression.
- Largest *regional* pyroclastic deposits (>1000 km^2):
  - Mode of emplacement less clear; for the Aristarchus Plateau deposits, very high effusion rate eruptions leading to sinuous rilles and associated pyroclastic emplacement have been implicated.

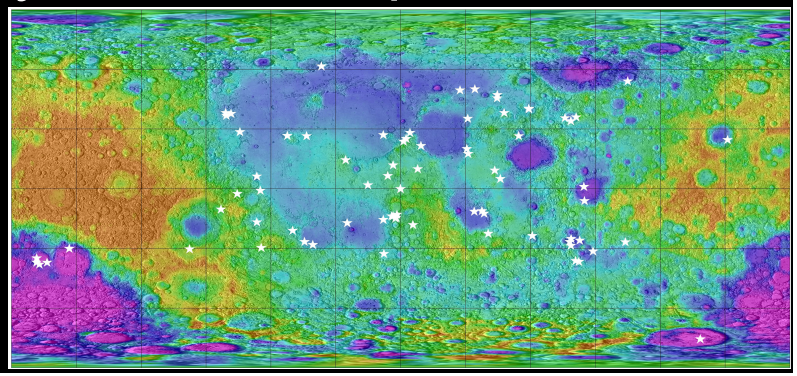


(Head, 1974)

(Head et al., 2003)

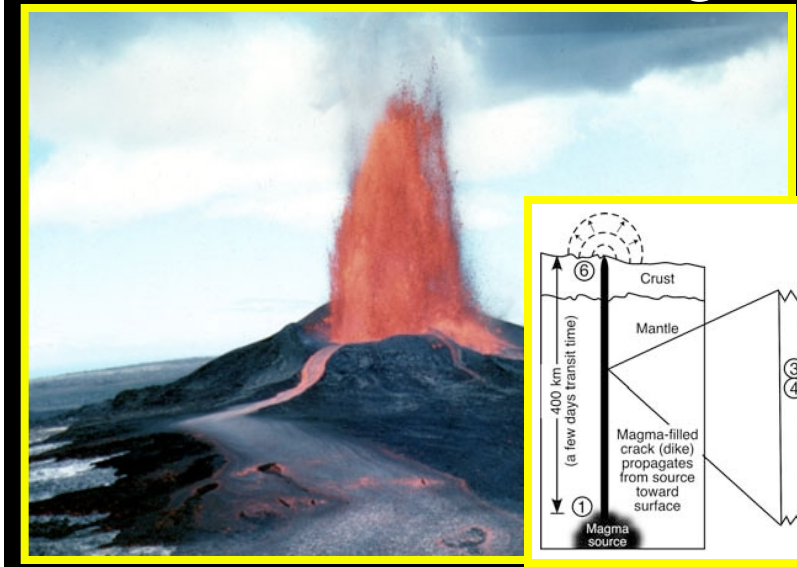


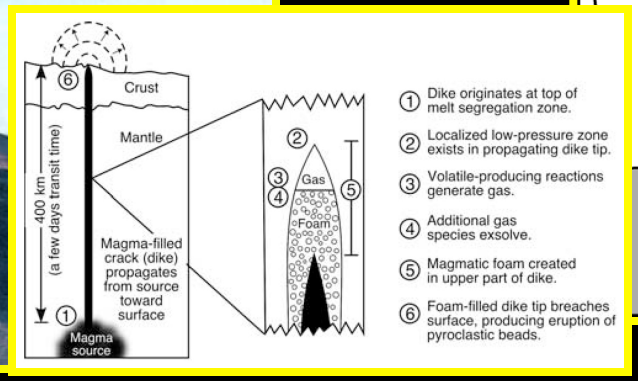
(Gaddis, 2003)

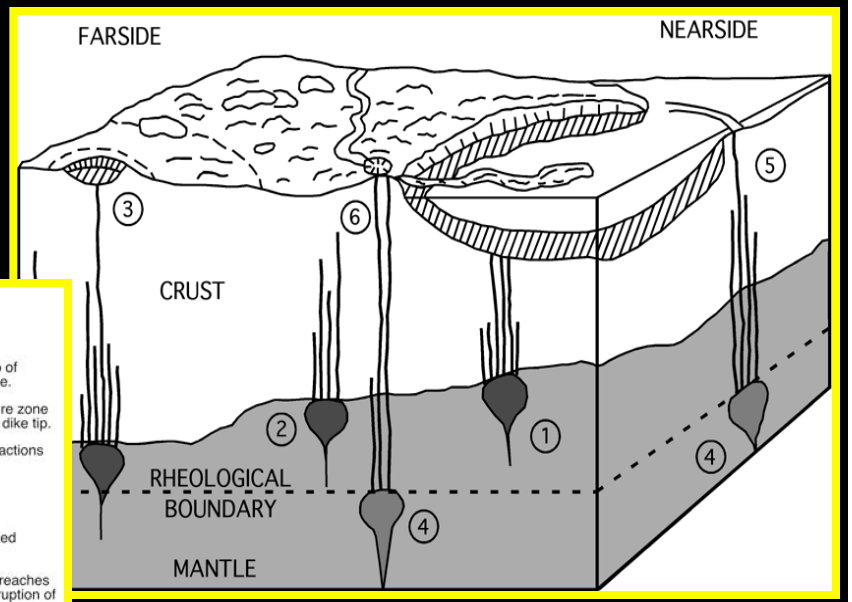


Sources of Volatile Formation and Buildup

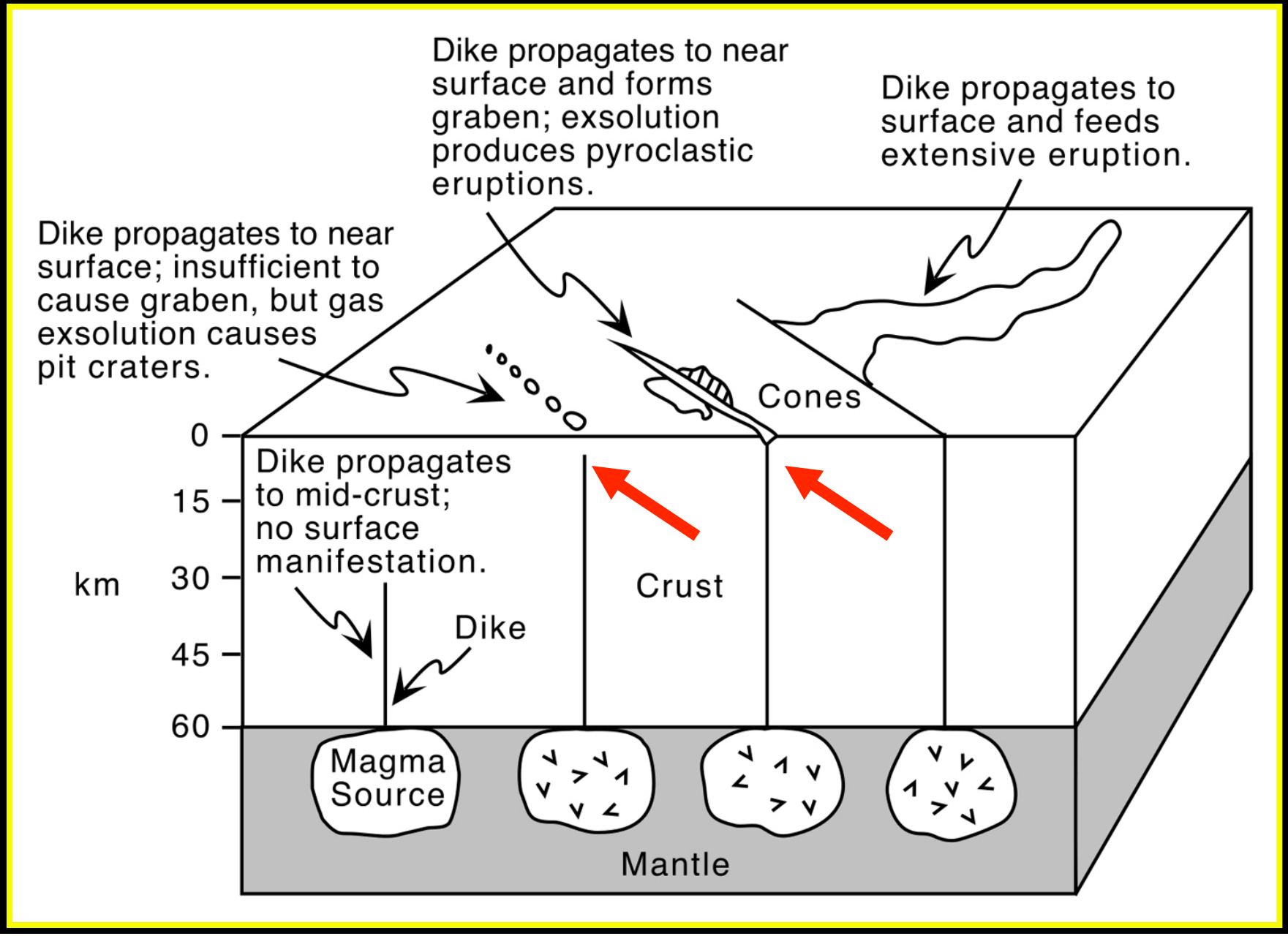
- Volatile content of mantle source rock.
- Dike tip low-pressure zone.
- Shallow pressure-dependent gas exsolution.
- Shallow pressure-dependent chemical reaction: Onset of smelting produces CO at 40 MPa, 10 km.
- Shallow fractionation processes.
- Volatile loss during eruption.



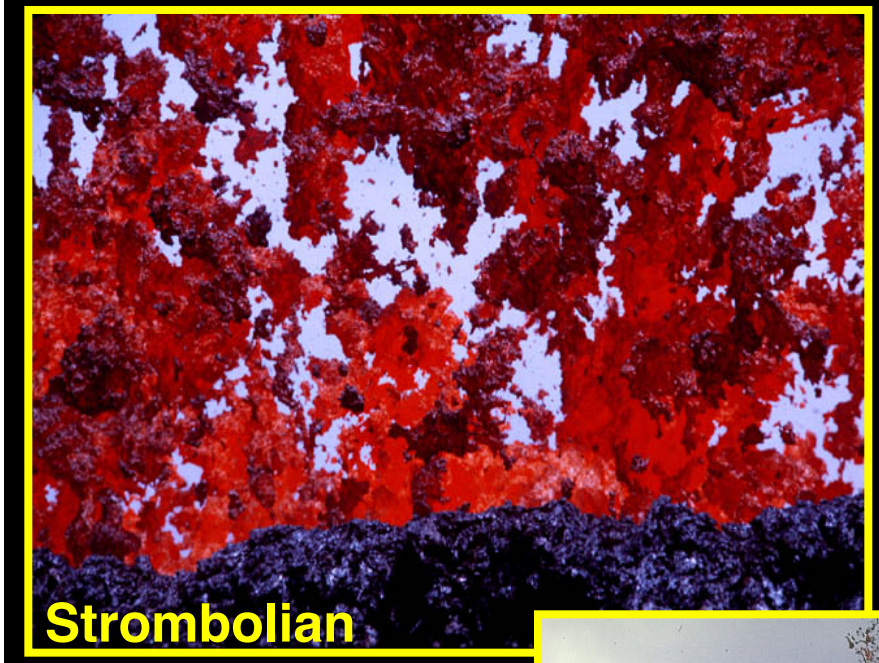




Shallow Fractionation Processes



Styles of Pyroclastic Eruptions

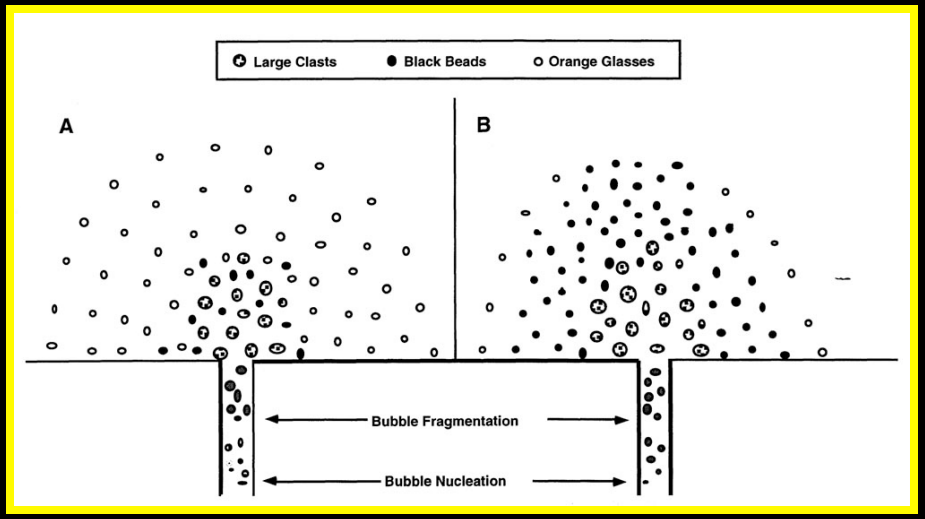


- Hawaiian:
- Strombolian:
- Vulcanian:
- Plinian:
- Ionian:

Pyroclastic Dark Mantle Deposits: Modes of Origin

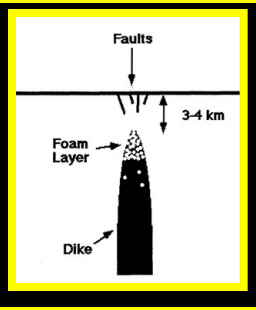
1. Models for formation of RDMD focused on pyroclastic volcanic eruptions (Wilson and Head, 1981):

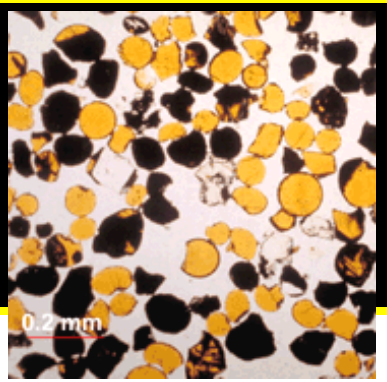
-Venting of volatiles into vacuum during high effusion rate eruptions caused wide dispersal of pyroclastic beads due to low gravity and lack of atmosphere (no drag).



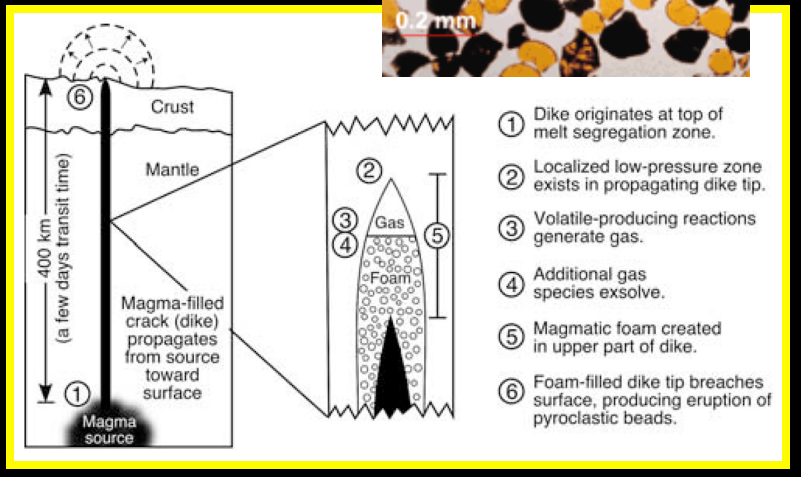
2. Models for formation of smaller DHCs focused on association with graben and vulcanian eruptions (Head and Wilson, 1979):

-Dikes stall at shallow depth, cause graben, gas builds up, causes explosive venting.





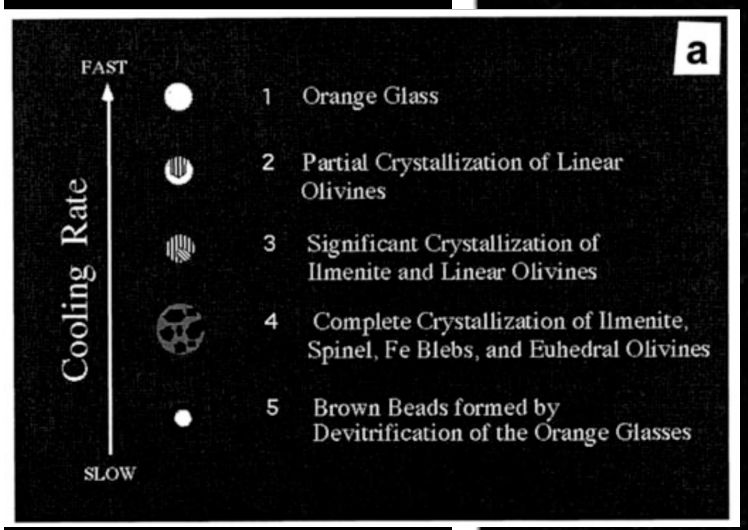
3. Low-pressure in dike tip causes volatile production during ascent, foam buildup. (Wilson and Head, 2005).

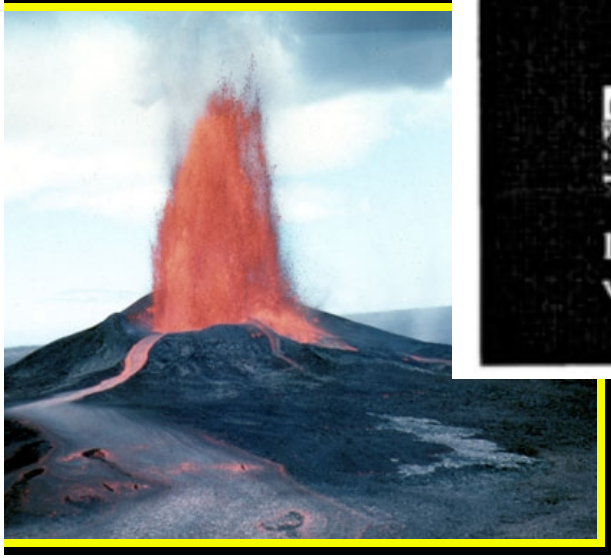


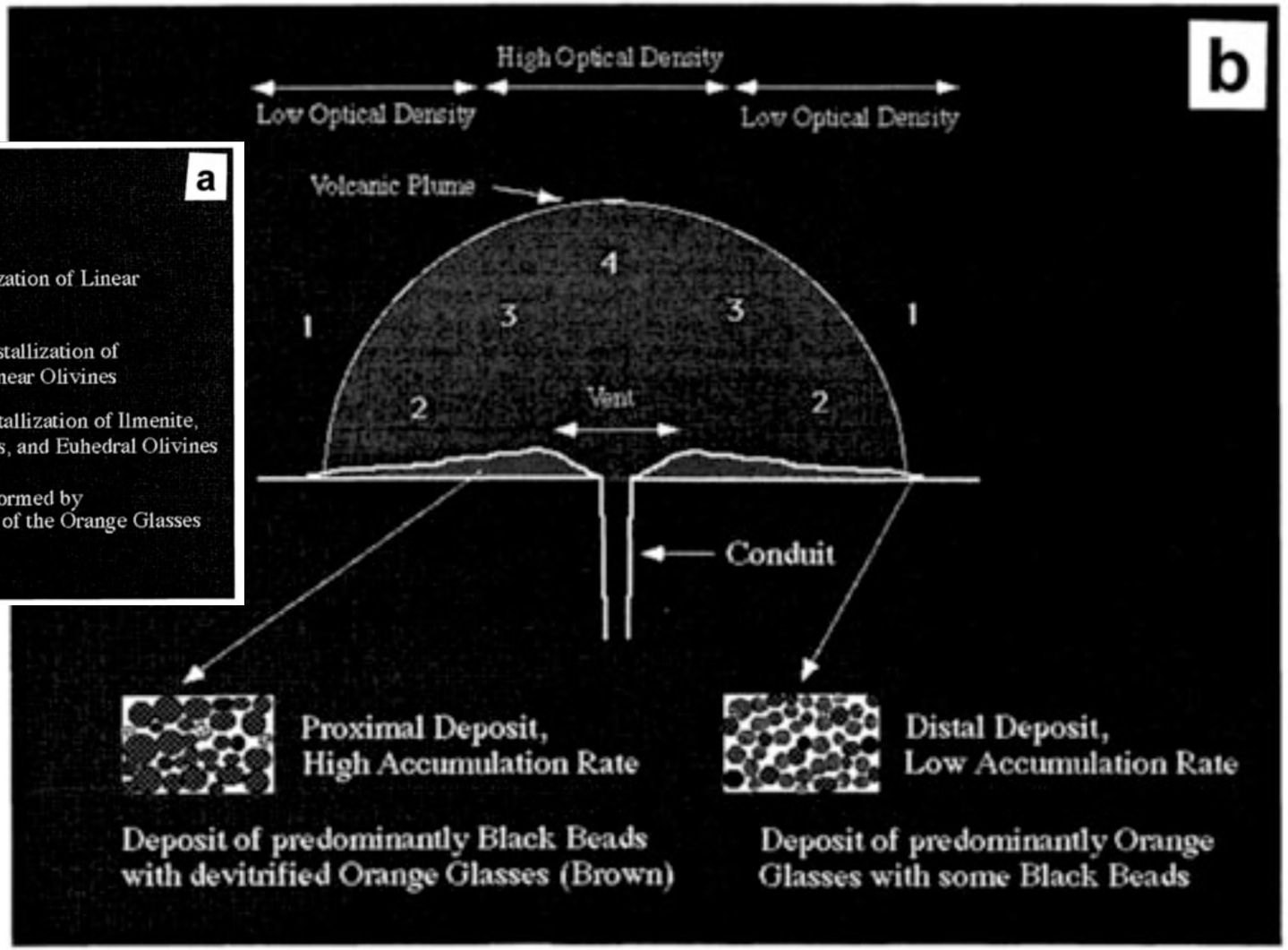
4. Apollo 17 mission to Taurus-Littrow DMD:

-Showed that DMDs composed of high-Ti submillimeter pyroclastic volcanic beads.

Eruption Plume Optical Density



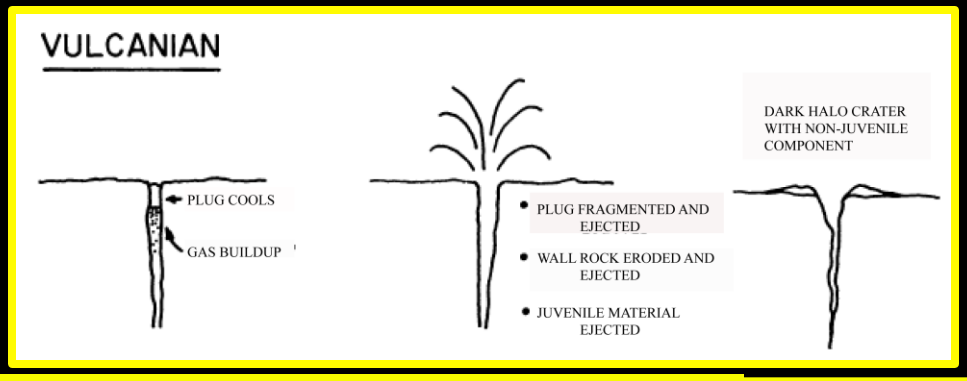


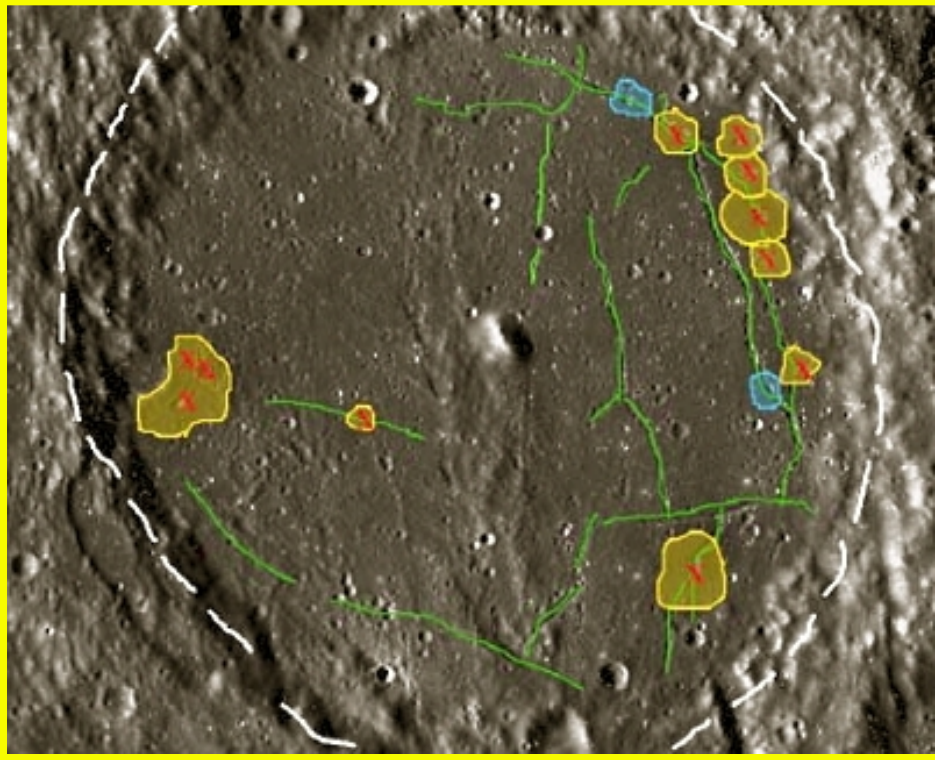


(Weitz et al., 1998, 1999)

Lunar Pyroclastic Deposits:
Linked to lunar versions of vulcanian activity.

Small scale: Floor of Alphonsus





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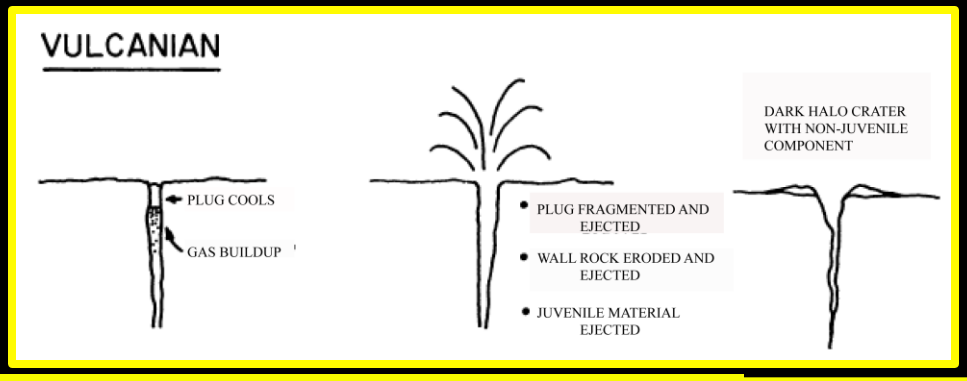
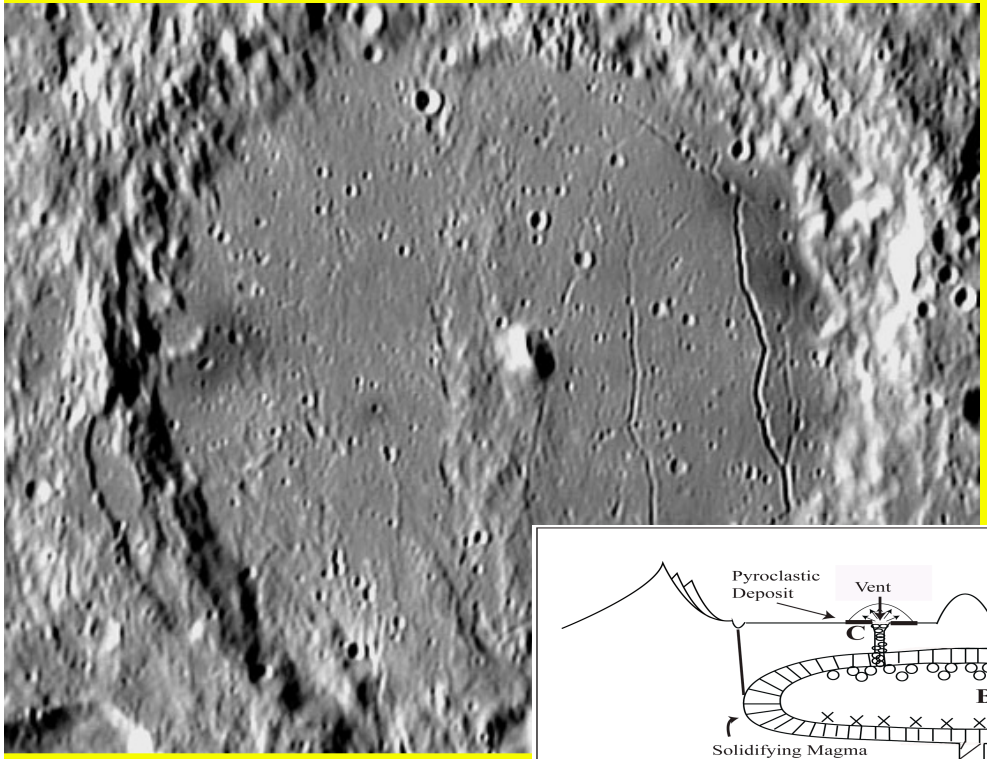
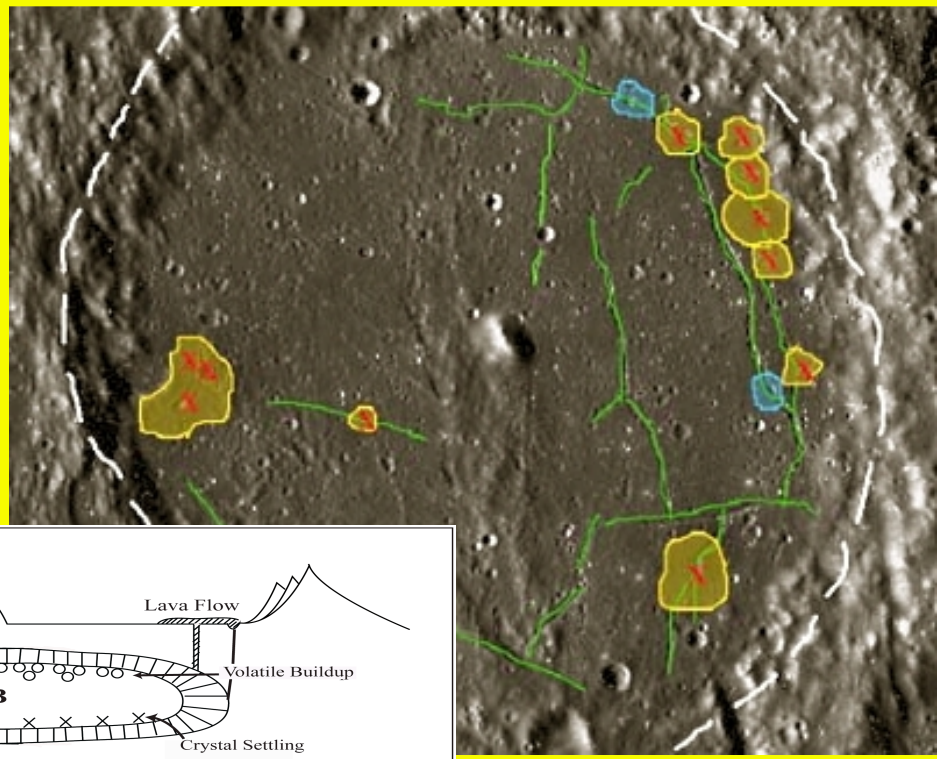
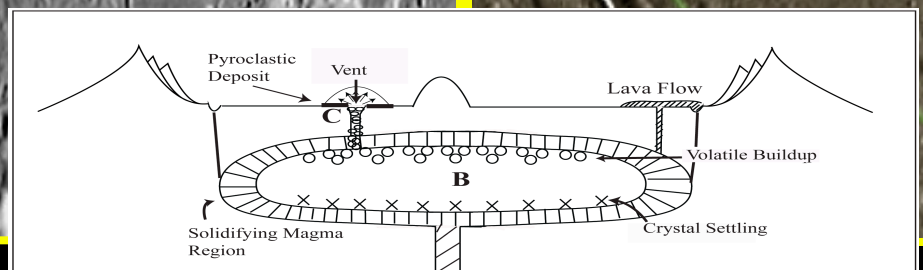
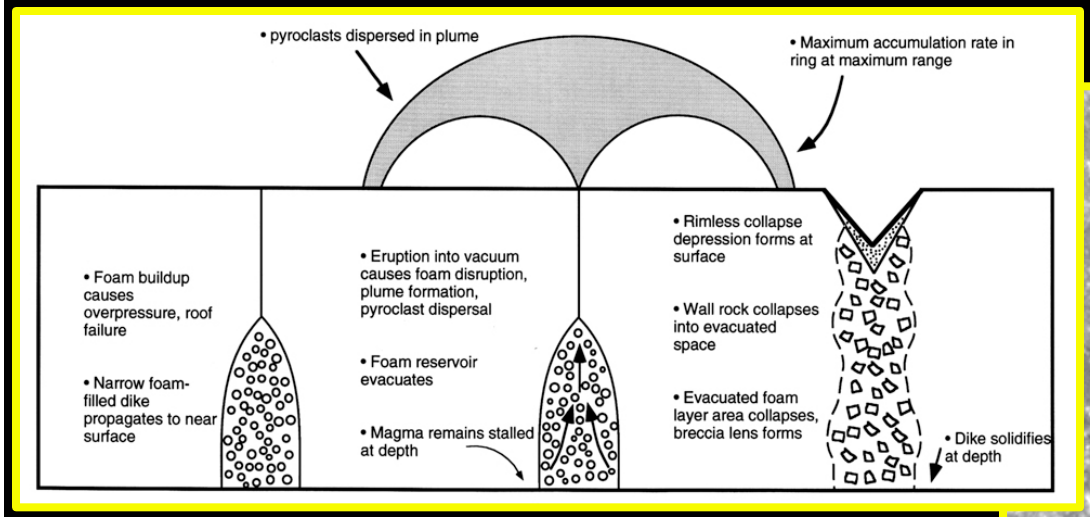


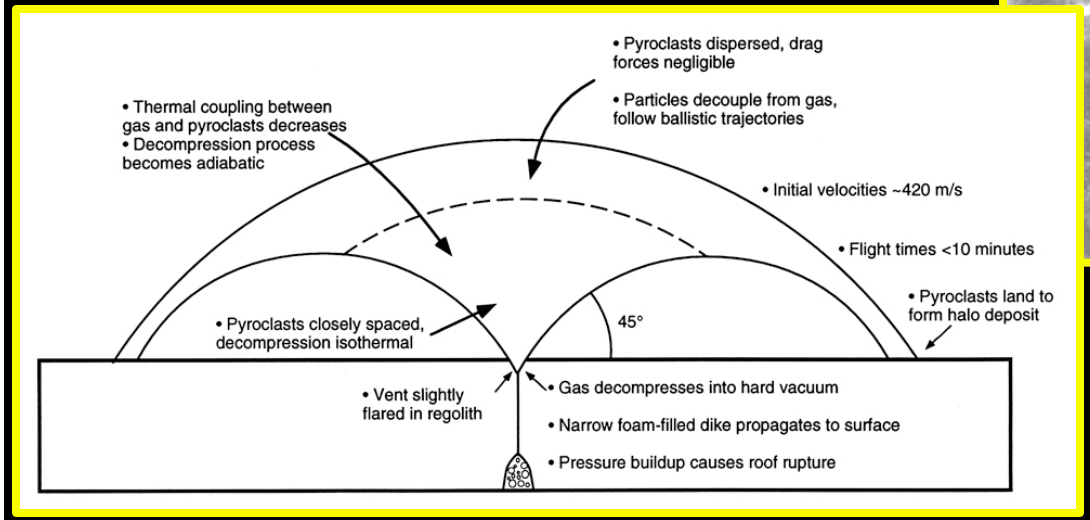


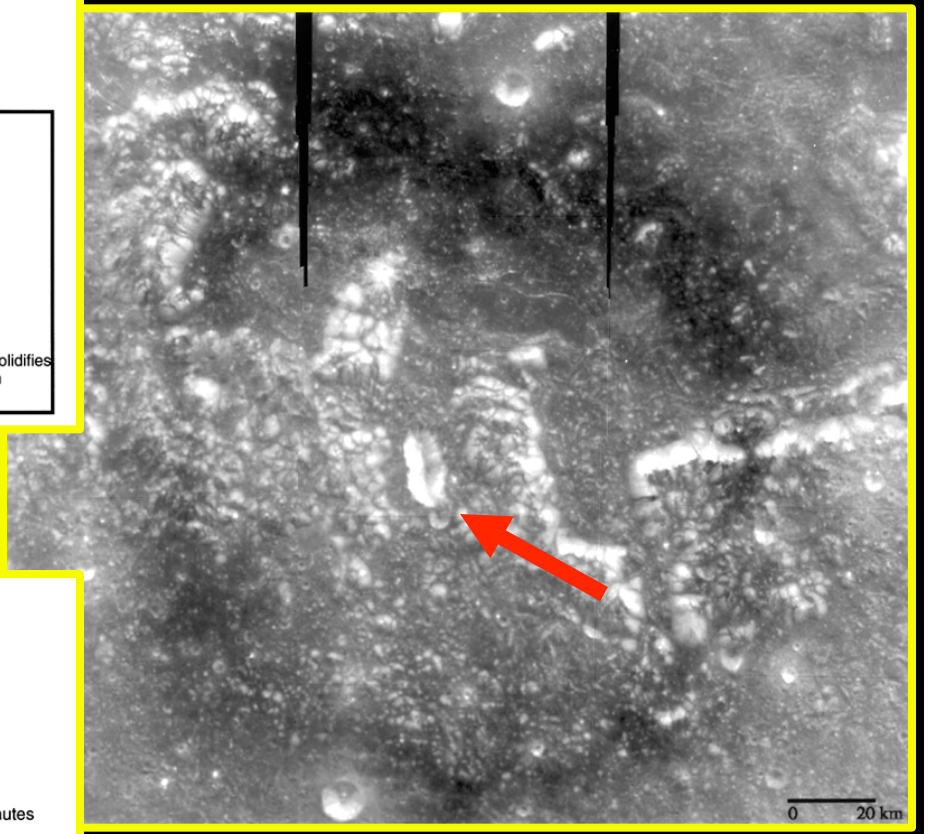




Lunar Pyroclastic Deposits:
Linked to lunar versions of vulcanian activity: Ionian







Large scale:
150 km diam. "dark ring"
in Orientale Basin.

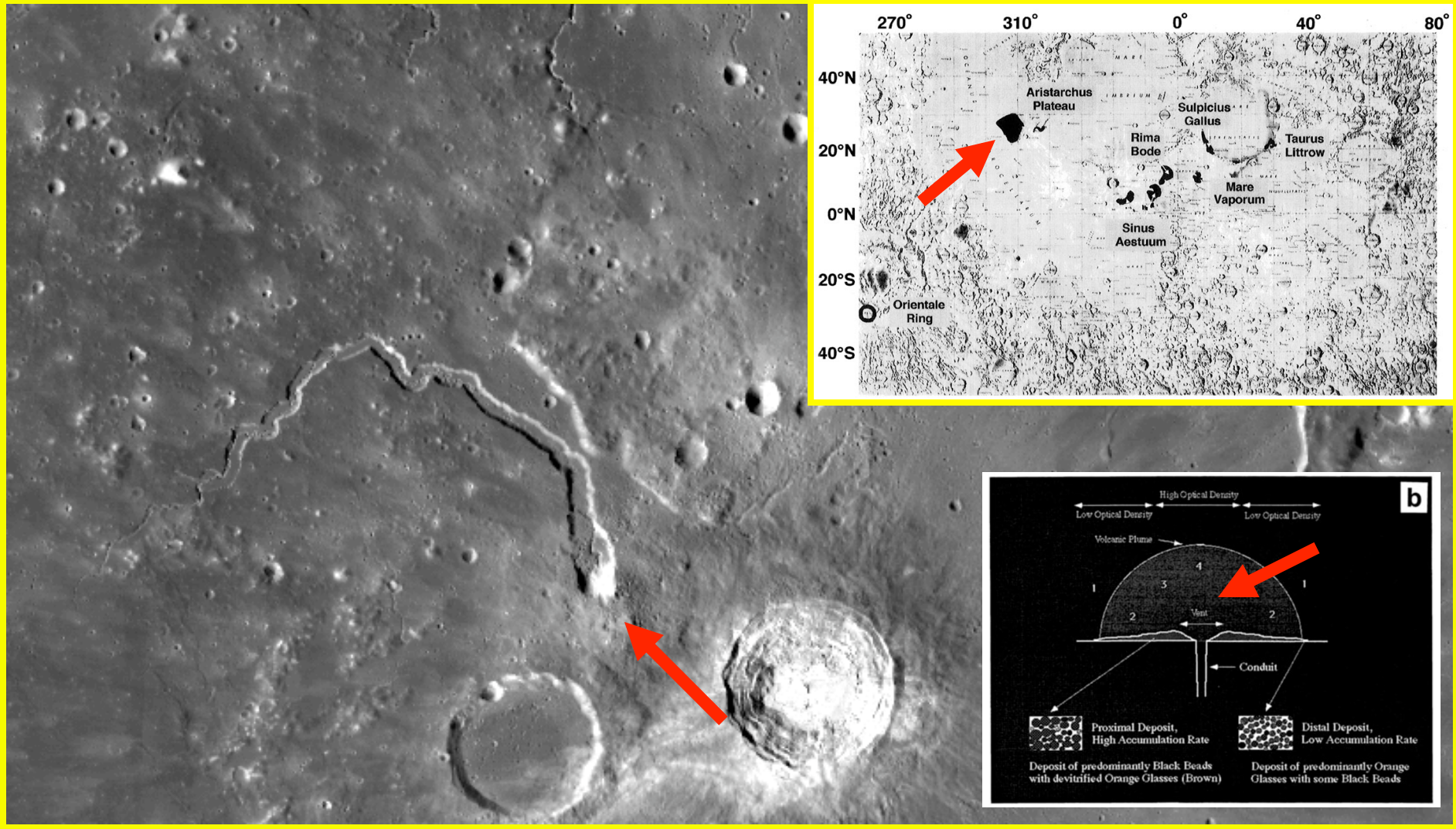
Lunar Pyroclastic Deposits: Linked to lunar-type hawaiian/strombolian activity.

Hawaiian

Strombolian

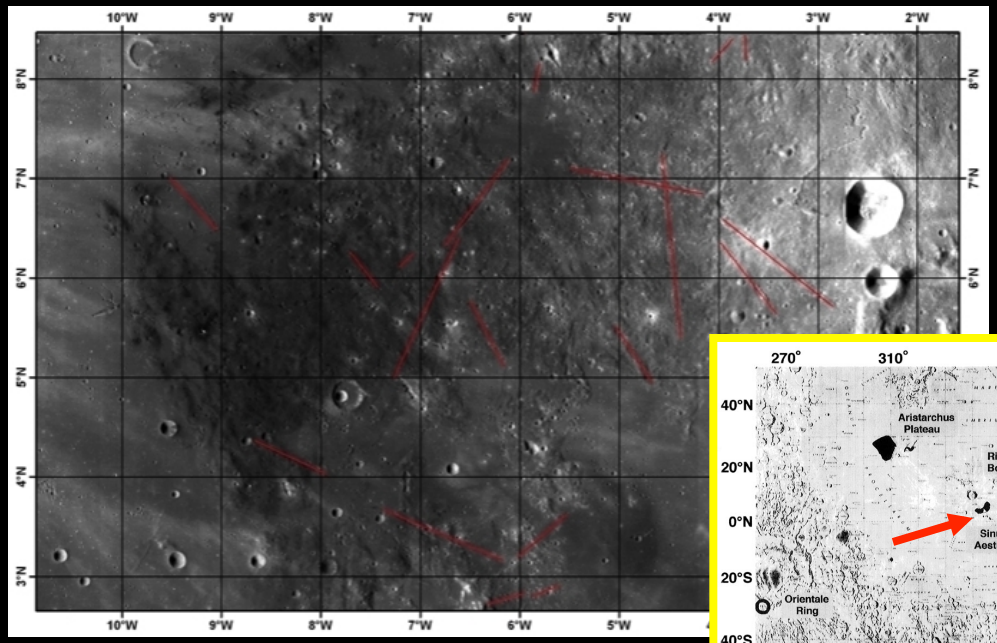
Lunar Pyroclastic Deposits: Linked to lunar-type hawaiian/strombolian activity.

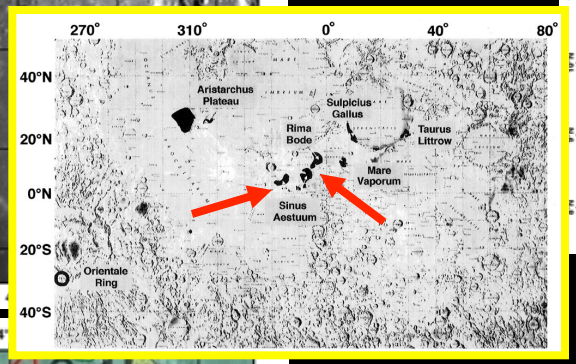
Aristarchus Plateau-Regional Pyroclastic Deposits

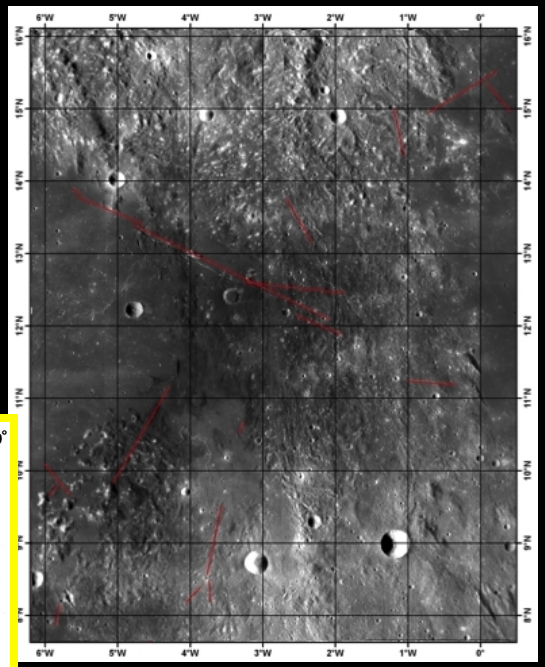


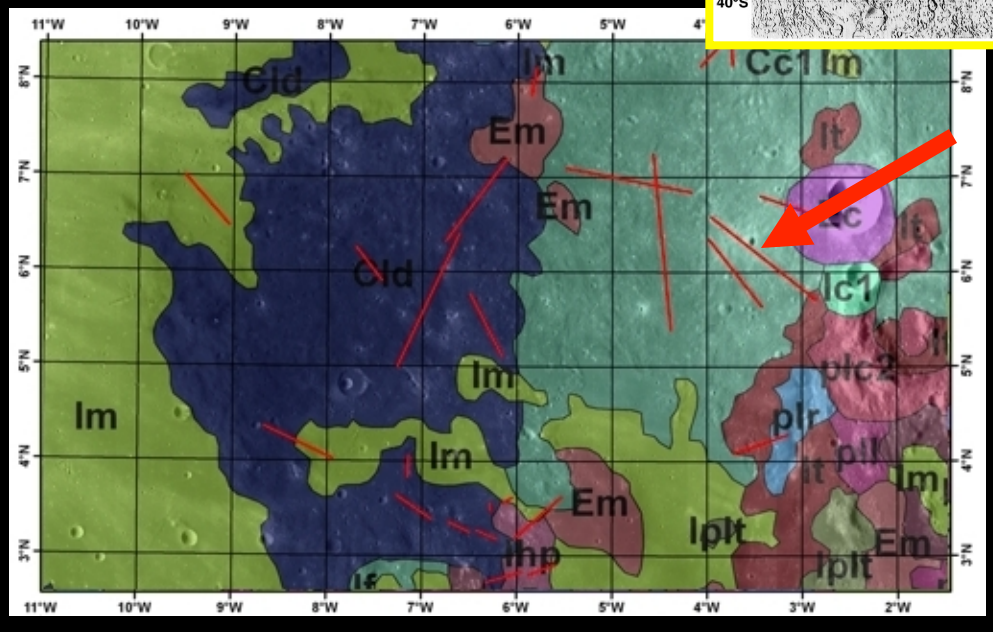
Examples of regional pyroclastic deposits linked to graben: Linear Rilles.

Rima Bode

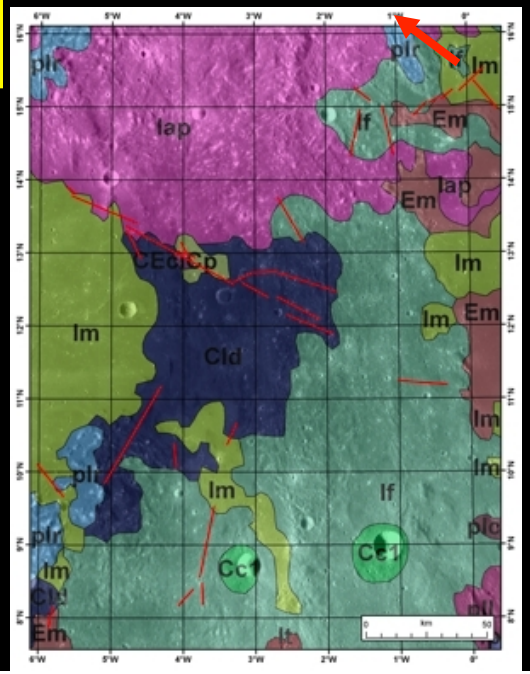




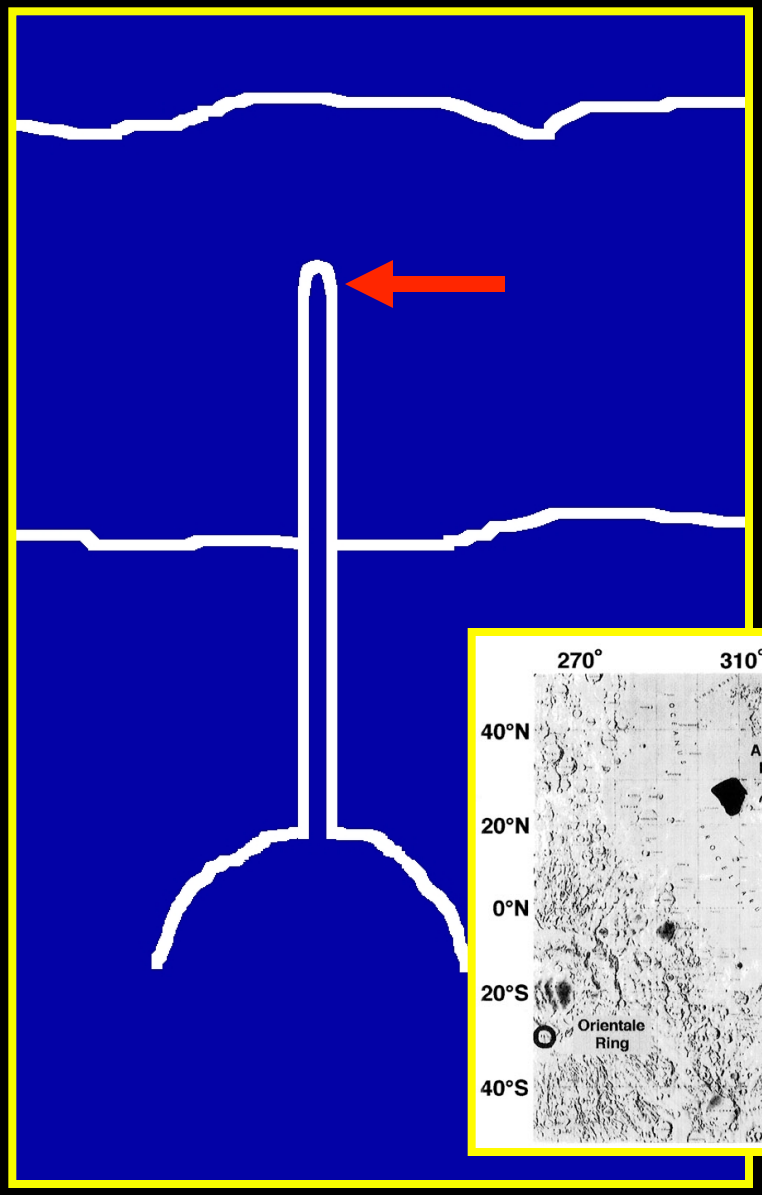


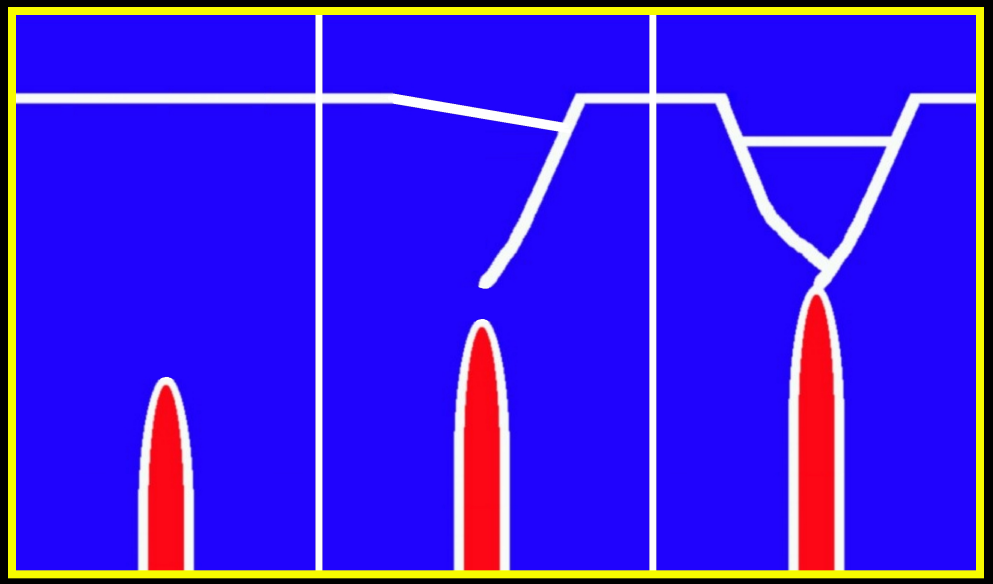


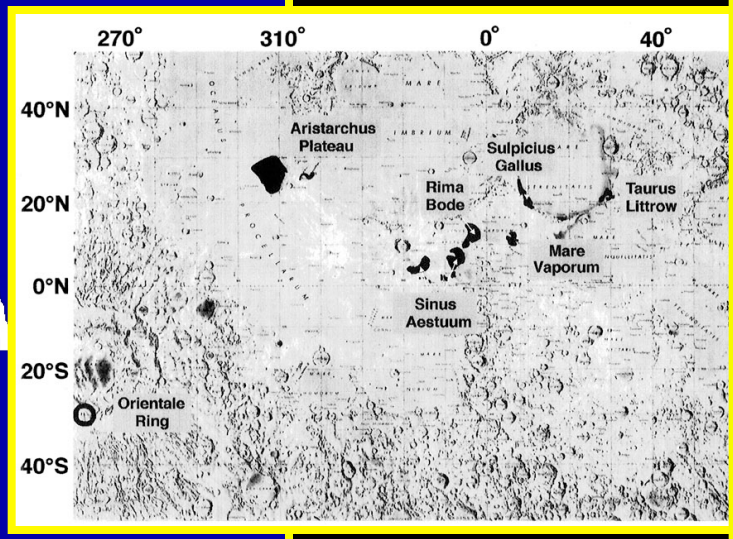
Sinus Aestuum



Shallow intrusions induce surface graben:







Pyroclastic Eruption Dynamics

-Ranges of pyroclasts are typically up to 100 km.

-Using $R = v^2 / g$ this implies v = 403 m/s.

-Gas content: Assuming 2000 ppm CO, 700 ppm H_2O, 325 ppm SO_2 ,traces of F, Cl: v = 117 m/s, R = 8.45 km (not 100 km!).

-$R \propto v^2 \propto n$, so a 12-fold gas concentration must occur.

-But: What if Gas Fractionation Occurs:

-If a 100 km long graben is formed over a 300 m wide dike;

-80% CO foam occupies a 10 km vertical depth, i.e. a volume of $10 \times 100 \times 0.3 = 300$ km^3 = 3 x 10^{11} m^3.

-If all of the 60,000 ppm gas is used to drive the eruption:

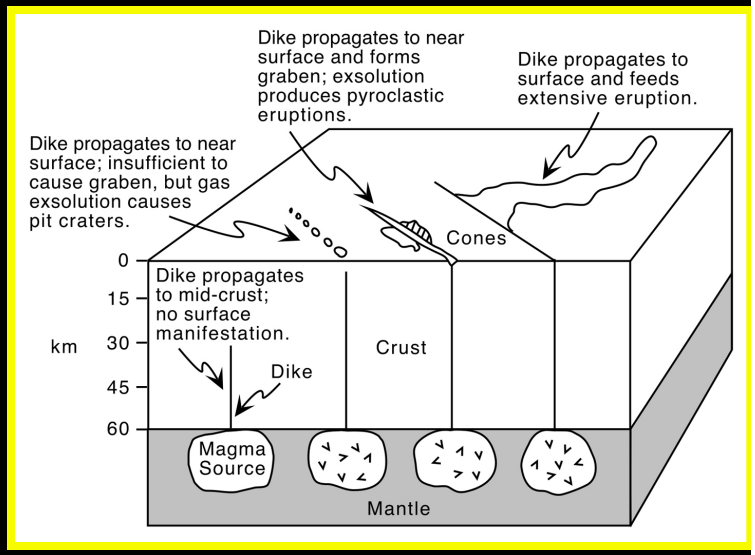
-v = 534 m/s, range = 176 km.

-Area = 2×176 km x 100 km = 3.52×10^{10} m^2.

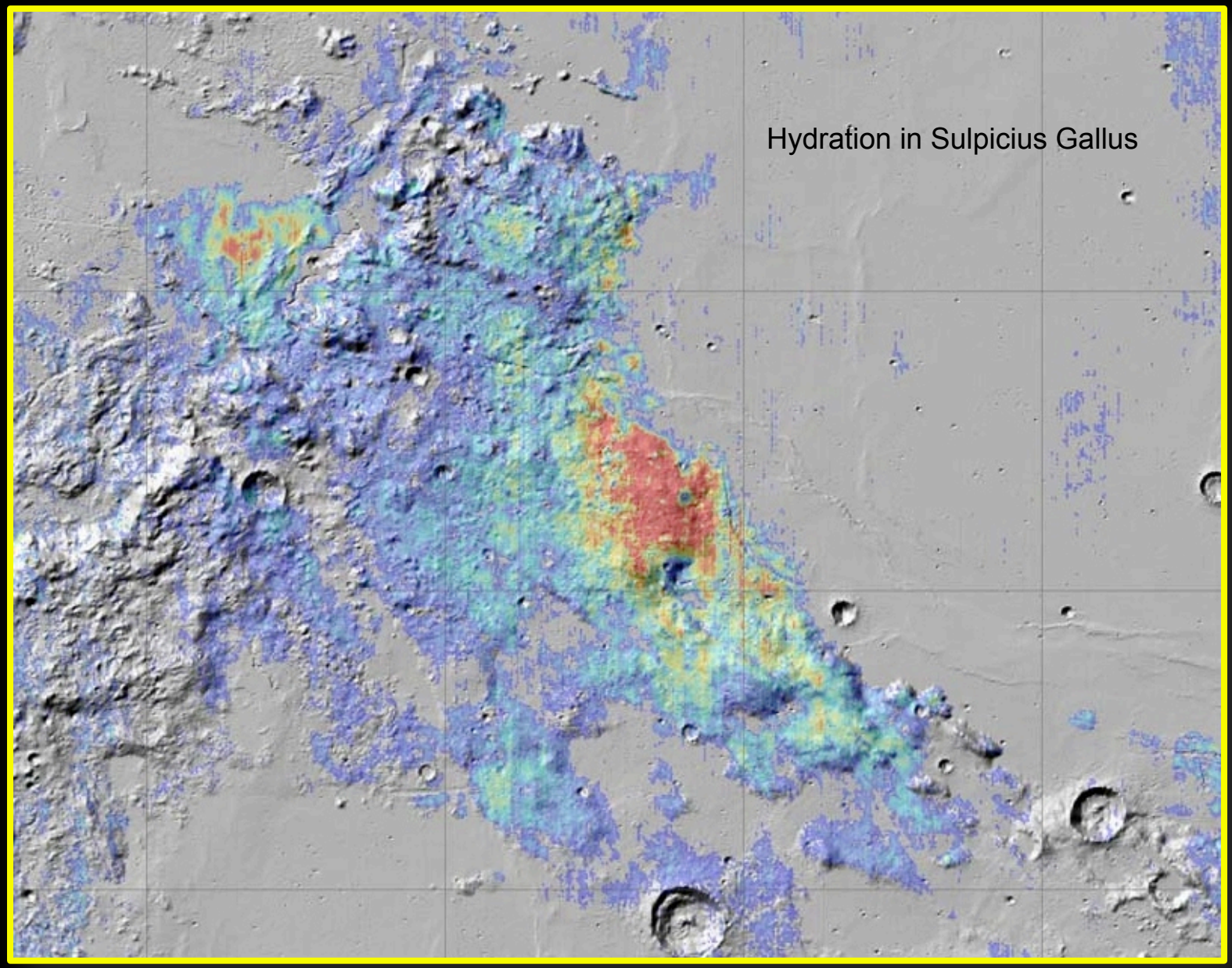
-Concentration factor is ~22.

Lunar Regional Pyroclastics: Conclusions:

- Gas concentration in *foams at the tops of shallow dike intrusions* should have been common on the Moon.
- It would have been easy to produce ~ *meter- thick pyroclast layers* over 100 km x 100 km areas.

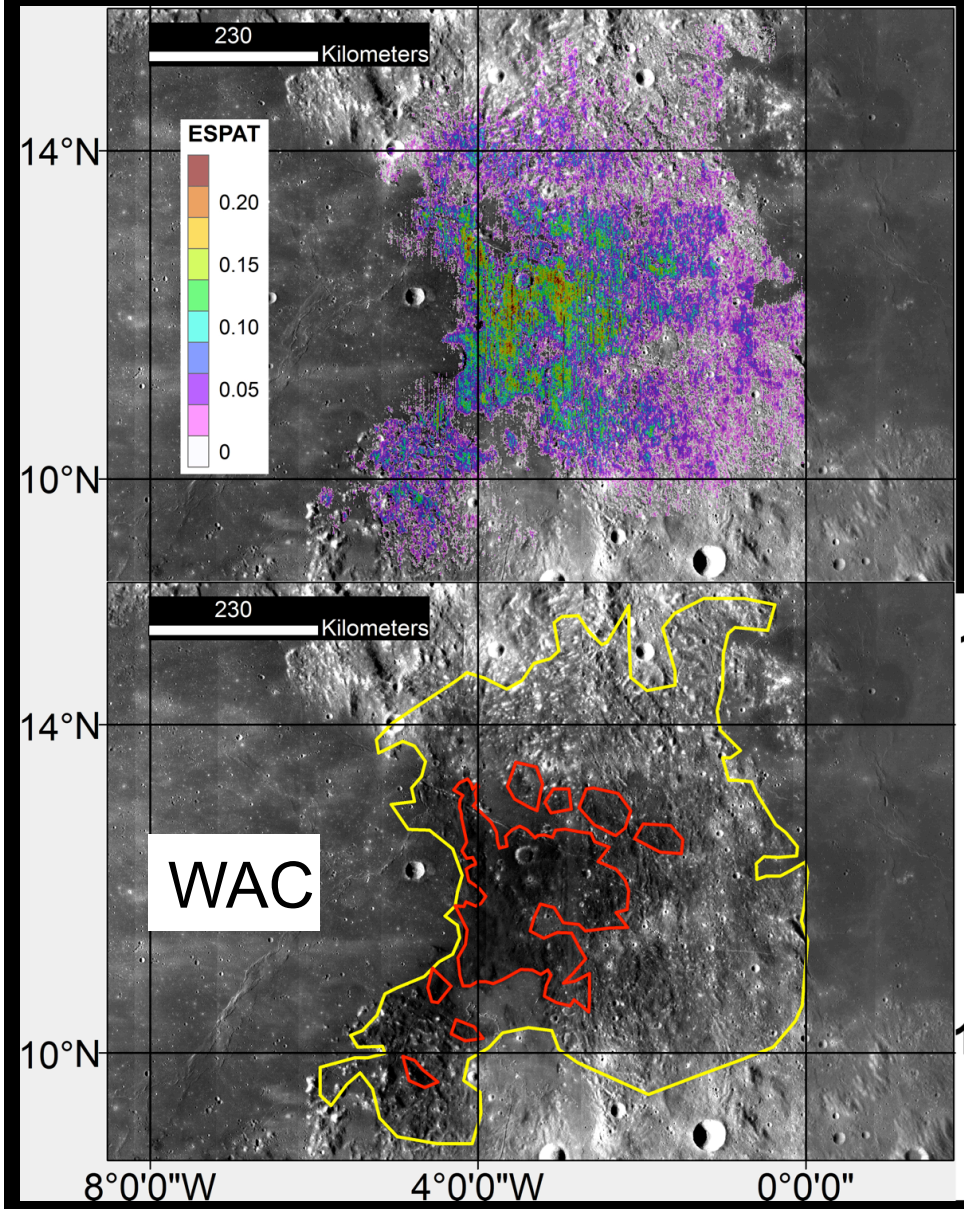


Quantify surface hydration - M^3 data: Improved thermal correction:



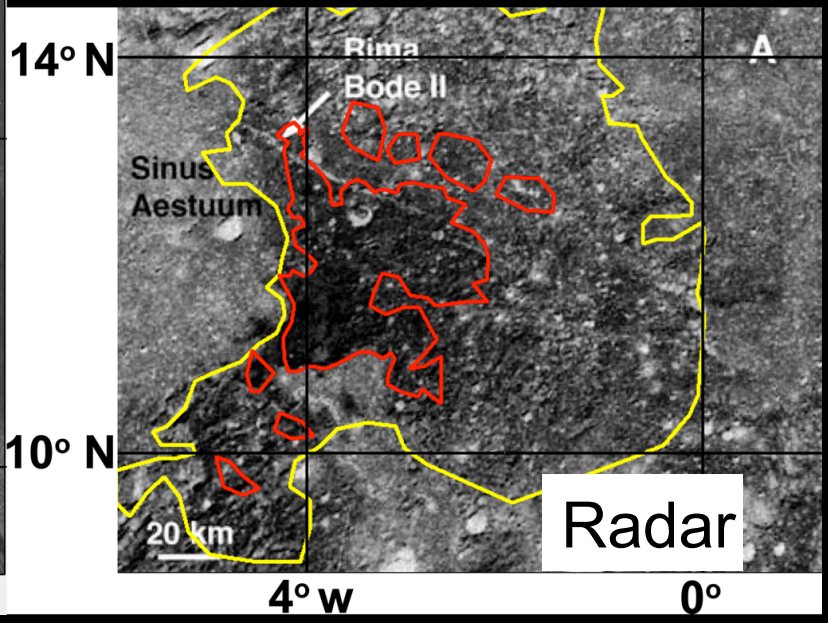
Shuai Li and Ralph Milliken, Brown University

Moderately Hydrated Deposits (Rima Bode)



Li et al., 2014

- High hydration regions correlate well with dark areas shown in WAC and S band Radar CPR image.
- Localized high hydration spots might provide clues for identifying vents.
- Average 'water' abundance: ~200 ppm



Carter et al., 2009